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Review

A comprehensive review of the environmental impacts of hydropower projects in Sarawak, Malaysia

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ABSTRACT

Sarawak is a state in Malaysia that has many potential sites for hydropower dams as Sarawak houses many hilly areas which are yet to be developed. As a result, many hydropower dams were proposed in Sarawak. This paper reviews the environmental and social impacts of hydropower projects in Sarawak. The murky river waters of Sarawak contributed to a high level of sedimentation in the hydroelectric plant reservoirs which increases the emission of greenhouse gases through mineralization and indirectly affects the lifespan of a hydroelectric plant. The ecosystem is adversely affected by the loss of trees, destruction of habitat for flora and fauna, and the narrowing of rivers due to sedimentation. The construction of hydropower plants forces nearby indigenous communities to relocate, which are given compensation by the Sarawak government. The issues behind the relocation process are explored in this paper with further details. The communities that are affected by the construction of the hydropower dams will have to be displaced from their original lands; thus, the approach by the government to compensate the affected locals in Sarawak is explored in this paper.

1. Introduction

Hydropower is widely utilized all over the world as it provides multiple benefits to various countries. For example, Nigeria utilizes hydropower as a decentralized power source to solve the country's limited power supply [1]. On the other hand, China has built more than 47000 dams all over the country [2, 3], including the biggest dam in the world namely the Three Gorges Dam which can produce up to 84.7 billion kilowatt-hours per year of electricity, equivalent to the amount of energy that could be produced by burning 50 million tons of coal [4]. Another country that also utilizes hydropower would be Malaysia. Malaysia has multiple dams throughout the nation, with Sarawak generating most of the hydropower energy [5, 6]. Sarawak is a state in Malaysia situated on the island of Borneo that is blessed with a vast number of rainforests. The Bornean rainforests hold biodiversity of flora and fauna, boasting an estimated 4% of the world's plant species and 5% of the world's birds and mammals, consisting of 222 species of mammals, 420 species of birds, 3000 tree species, and 15000 flowering plant species [7]. Over the past few decades, there has been a surge in the development of lands in Sarawak, which is the largest state in Malaysia out of the thirteen [8]. This has led to an increase in power demand in Sarawak. Initially, fossil fuels such as diesel, coal, and natural gas were used for the power plants in Sarawak, meeting the power demand of 1250 MW based on the year 2015 [9]. However, due to diesel, coal, and natural gas being non-renewable resources, sustainable approaches to generating renewable energy were introduced. One of them is hydropower generation. It is estimated that 12 hydroelectric power plants and two coal power plants will be built in Sarawak by 2030 with a total capacity of 9380 MW to cater to the increasing power demand in the future [9]. Although hydropower generation is praised for being a sustainable renewable source of electricity generation in Sarawak, the construction of HEPs will inevitably affect the environment in terms of environmental degradation and water quality deterioration [10-19].

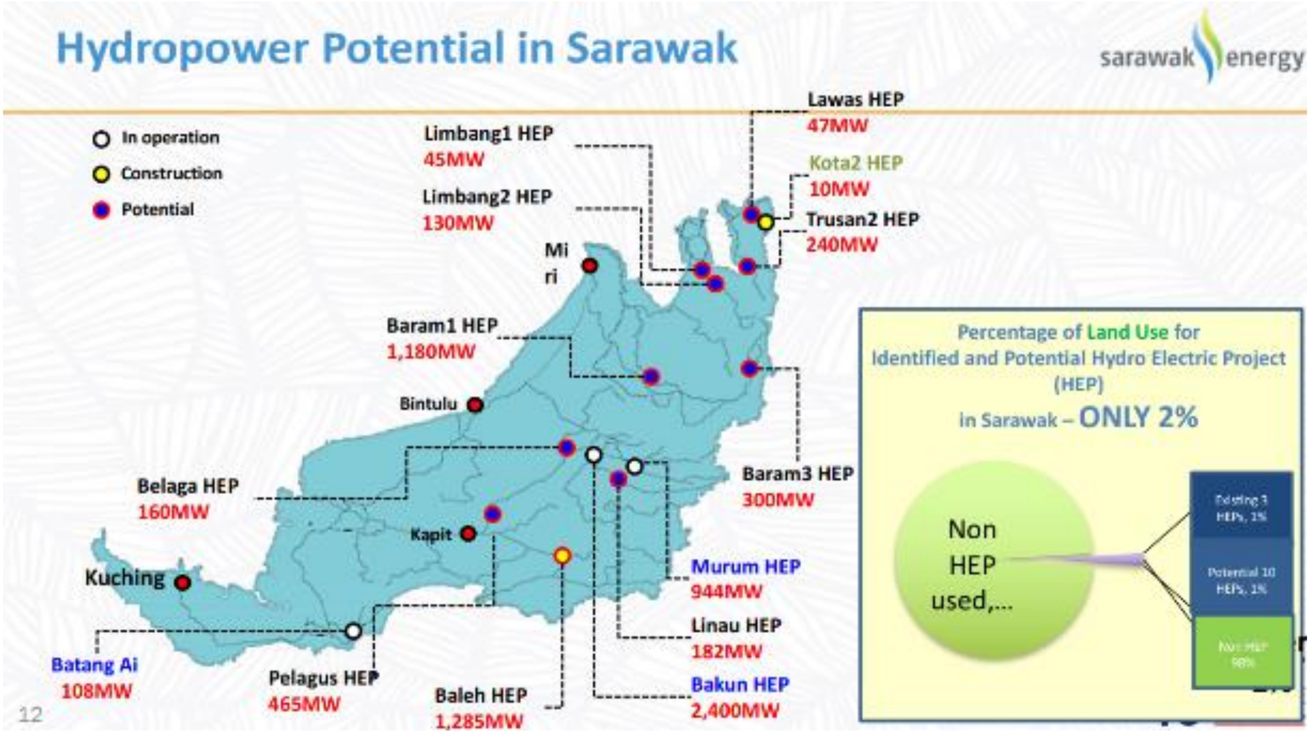

Figure 1: Hydropower plants in Sarawak in 2017 [20]

1.1 Power generation in Sarawak

Sarawak is a powerhouse when it comes it hydropower generation in Malaysia. With the geographical advantage of Sarawak in favor of hydropower, there are many potential sites for hydropower plants, as shown in Figure 1. As of 2021, there are three major hydropower plants operating in Sarawak, which are the Bakun, Murum, and Batang Ai HEP. Figure 2 shows the state of the Bakun Dam in 2010. Baleh hydropower plant is also another major hydropower plant currently under construction which is expected to be operational in 2026. Aside from these major hydropower plants, Sarawak has coal-fired, gas, and diesel major power plants. The summary of which can be found in the table below. According to Table 1, the majority of Sarawak's power generation is from the renewable source of energy with hydropower as the source of generation, totaling about 57.1%, excluding ongoing projects, after the commissioning of the Tanjung Kidurong Extension project [21]. After the completion of Baleh HEP, hydropower will be contributing 64.6% of the total power generation of major plants.

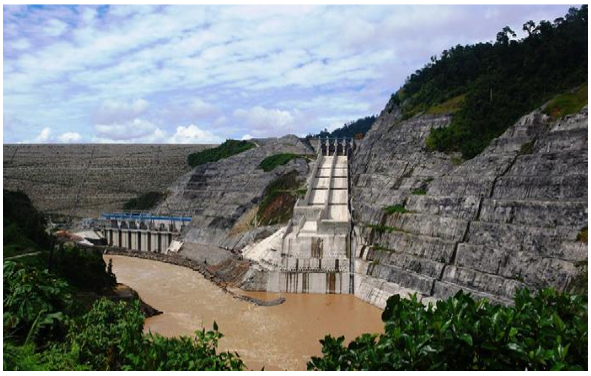

Figure 2. Bakun Dam in Sarawak, Malaysia [22]

1.2 Sarawak Corridor of Renewable Energy (SCORE)

The Malaysian Federal Government created five economic development corridors to stimulate global and domestic industrial investments, and SCORE is one of them. The objectives of SCORE are to secure a total of RM334 billion of private and public investments by 2030 for the development of Sarawak [23]. The corridor spans a length of 320 km [24]. These industrial zones will then be supplied with an inexpensive and renewable source of energy harnessed from hydropower plants. Under SCORE projects, there are a total of twelve mega-dams proposed in Sarawak to sustain the developments under SCORE, two of which are already completed with the third one under construction. The first dam to emerge from this project, the Bakun dam, has an impoundment area of 720 km^2, which is roughly about the size of Singapore [22]. Followed by Bakun dam is Murum dam with a reservoir size of 245km^2 and lastly, Baleh Dam will have a reservoir size of 588 km^2 [25].

2. Environmental Impacts of Hydropower

Given that hydroelectric power is a type of renewable energy, it releases a very small amount of carbon into the air [5]. According to [20], the carbon intensity of the electricity supply in Sarawak has decreased by 72% as depicted in Figure 3. The water supply can also be used as drinking water and irrigation for agricultural usage. Hydropower also helps in storing water which protects aquifers from depletion. This will reduce the frequency of floods and droughts. However, the water supply and irrigation can reduce the water available for power generation and therefore reduce the power generation output [26]. Being a type of renewable energy, hydropower plants do not produce any waste, unlike coal or fossil fuel power plants. Not to mention that it can prevent excess GHG (greenhouse gases) emissions. Thus, air pollution is reduced along with the frequency of acid rain and smog occurring in the state.

2.1 Sedimentation and GHG emissions

Most rivers have a balanced inflow and outflow of sedimentations which controls the accumulation of sediments in the river [27]. When the river is impounded, the imbalance will accumulate sediments [28]. Sedimentation in the impoundment area of the hydro dams contributes to GHG emissions through the mineralization process where it decomposes to produce CO_2 (carbon dioxide) and CH_4 (methane). Reservoirs with higher sediments raise aquatic weeds such as algae, and other plants, which increases the emission of carbon dioxide up to 0.03 pounds [29]. Additionally, the formation of large dam reservoirs increases the emission of greenhouse gases through the decaying of biomass from the vegetation in the large, flooded areas [26]. Although hydropower is considered a clean source of energy since it produces significantly fewer emissions compared to coal, hydropower has a 'stored' potential of GHG emissions that lies dormant within the sedimentation in its reservoirs [30].

Table 1. List of major power plants in Sarawak according to Sarawak Energy Berhad [21]

Plant	Type	Power Generation (MW)	Status
Batang Ai Hydroelectric Plant	Hydro (Concrete Face Rockfill Dam)	108	Commissioned
Murum Hydroelectric Plant	Hydro (Concrete Face Gravity Dam)	944	Commissioned
Bakun Hydroelectric Plant	Hydro (Concrete Face Rockfill Dam)	2400	Commissioned
Baleh Hydroelectric Plant	Hydro (Concrete Face Rockfill Dam)	1285	Ongoing (2026)
Bintulu Kidurong Power Station	Gas Combined Cycle – 317MW Open Cycle – 165MW	482	Commissioned
Bintulu Tanjung Kidurong Extension – Combined Cycle Gas Turbine	Gas	421 x2	Commissioning (2021)
Miri Power Station	Gas	102	Commissioned
Mukah Power Station	Coal	135 x2	Commissioned
Sejingkat Power Station	Coal	210	Commissioned
Balingian Power Station	Coal	312 x2	Commissioned (2019)
Kuching Power Station	Diesel	64	Commissioned

Uncontrolled release of the sediments during the decommissioning of hydro dam affects both upstream and downstream rivers which may potentially impact the aqua life and riffle-pool habitats, deposition downstream, destabilization of stream banks, and a large amount of GHG emissions [31, 32].

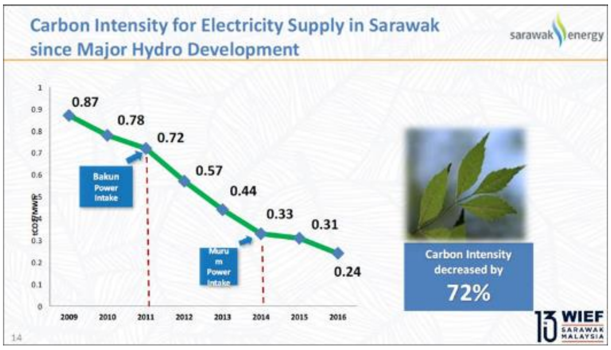

Figure 3. Carbon Intensity for Electricity Supply in Sarawak since Major Hydro Development [20]

The study conducted by Pacca analyzed the CO_2 emissions during the decommissioning of Glen Canyon Dam, and he found that if all sedimentations are mineralized during decommissioning, the CO_2 emissions amounted to 33,000,000 metric tons. To put this into a better perspective, the construction of the dam emitted 800,000 metric tons, while the emissions associated with biomass decay in the reservoir during its operation was 3,500,000 metric tons [32]. The estimated yearly CH_4 emission of major hydropower dams in Malaysia is 387,340,000 kg, with Sarawak contributing the majority of it at a total of 60.9% from Bakun, Murum, and Batang Ai dams, of which, Bakun dam contributed the most at 41.26%, followed by Murum dam at 14.54% of the total emission in Malaysia [25].

Sedimentation issue is especially serious in Sarawak due to the vast rainforest region that is prone to rainfall. The study in reference [33] revealed that logging activities impacted the water quality of the streams after rainfall in terms of the increase of suspended solids from 8.3mg/L to 104.1mg/L. Upstream logging, unsustainable agricultural methods, and erosion contributed to high levels of sedimentation, with Bakun dam reservoir recording more than 500mg/l of sediments or an annual inflow of 9,000,000 tons [22,24]. Sedimentation, if not controlled, can indirectly affect the lifespan of a hydropower plant by reducing the water storage capacity, increasing wear on machinery, and negatively impacting downstream rivers as the decommissioning of dams are motivated by maintenance cost, environmental or regulatory requirements [31, 34]. Concrete dams that are built according to standards can easily reach a lifespan of 100 years, while the hydromechanical components such as the gates and motors are up to 30 to 50 years [35].

2.2 Geological and Ecological Impacts

The construction of hydropower dams will include some degree of deforestation and land loss due to submersion. Figure 4 and Figure 5 show the forest geography before and after the construction of Bakun and Murum Dam. It is evident that a huge amount of deforestation took place for the establishment of both dams, and a huge amount of land was submerged underwater. This will result in the destruction of wildlife and cause some wildlife population loss. The construction of the Murum Dam had threatened the population of 300 rare and endangered species [6]. In 2018 itself, the remaining intact forest was at an estimated 7.72 million hectares, which was around 62% of Sarawak state, while the 13 hydroelectric dam projects will collectively impact 1.7 million hectares of forests in Sarawak [36].

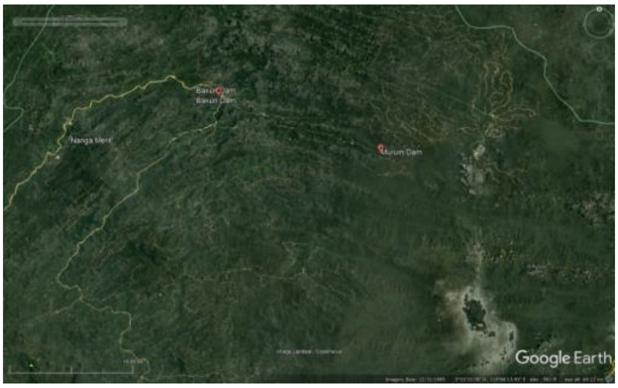

Figure 4. Location of Bakun and Murum Dam in 1995 before the construction

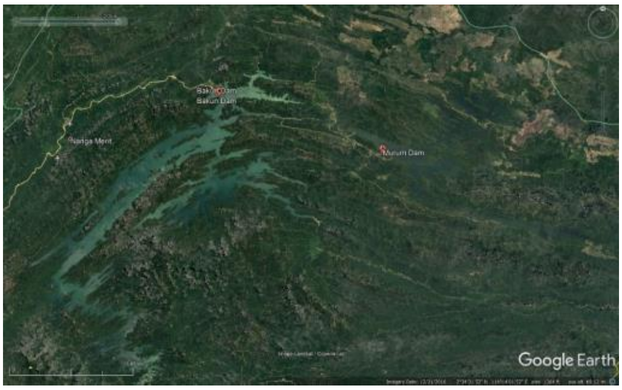

Figure 5. Location of Bakun and Murum Dam in 2016 after construction

Methods of rapid conversion where the areas deforested is replanted within a five-year period after clearance [37], cannot be applied here as the dams will drown out the once forested areas. As the hydropower plants in Sarawak are situated in rural areas, the transmission of the generated power would require the cutting of tall trees in the forests to cater to the Right of Way as shown in Figure 6 of the transmission lines [26]. The transmission lines proposed for Baleh HEP are rated at 500kV and will require an easement of 50 m. This transmission line has a span of 176 km in length and would total up to an area of about 880 hectares or 8,800,000 m^2 [38].

Other than that, the construction will bring destruction to the habitats of aquatic life and inhibit the migration of fish [5]. For example, the Bakun dam has a catchment area of 1.5 million hectares, and a reservoir area of 70,000 hectares will destroy six rare and endangered species of fish. Plus, the construction of the dam will change the hydrological regime of the area affected, and this will cause changes in water level, timing, and temperature [40]. This will severely affect the surrounding aquatic ecosystem. This also applies to all the protected flora and fauna, including the Silvered Leaf Monkeys and Bornean Gibbons. Plus, some hydroelectric dams will be located near certain protected areas, such as the Mulu National Park, which is home to one of the world's largest caves and a UNESCO World Heritage Site. Figure 7 shows the location of hydropower dams that will intrude on some protected areas in Sarawak if the dams are to be constructed in the future with no changes to their location.

2.3 Displacement of Communities

The construction of hydroelectric power plants in Sarawak affects the livelihood of communities downstream when large communities are forced to relocate [41]. These indigenous groups rely on the forest and river integrity for their daily lives. Not only will the construction of the dam force these people to relocate, but the act itself is also considered an ethnocide as it destroys the lifestyle that these communities have. Prior to relocation, the residents of Sungai Asap relied mostly on the forest for their sustenance. After their relocation, they can no longer rely on the forest but are tied to the cash economy, with wages that are not compatible with the living costs. The relocation of large communities living at the hydropower project site to new sites may involve deforestation as lands will be cleared to make way for new settlements [26]. Figure 8 shows the relocation of indigenous communities at the Bakun dam site to the resettlement area at Sungai Asap, which is situated about 30 km from the Bakun dam site [42]. Based on the statistics released by Sungai Asap District Office, the population affected by the Bakun dam in 1998 was 9428 people [42]. That population accounts for 26.75% of the people in the Belaga district in Sarawak.

2.4 Soil Erosion

A study was conducted by the United Nations Development Program, and it was found that fully developed dams in Sarawak could ruin the water quality and water levels [43]. This may lead to floods in the future. Aside from that, the construction of ongoing and planned hydropower dams will increase the number of landslides occurring in the region. Given that Sarawak has a tropical climate, rainfall frequently occurs throughout the state. Deforestation will remove the trees that are supposed to control the water levels through absorption. The rise in water-level, increased geological pressure, disturbances and deforestation will create favorable conditions for frequent landslides [36]. Figure 9 shows the areas in Sarawak that may be vulnerable to landslides if the planned hydroelectric dams were to be constructed as it is.

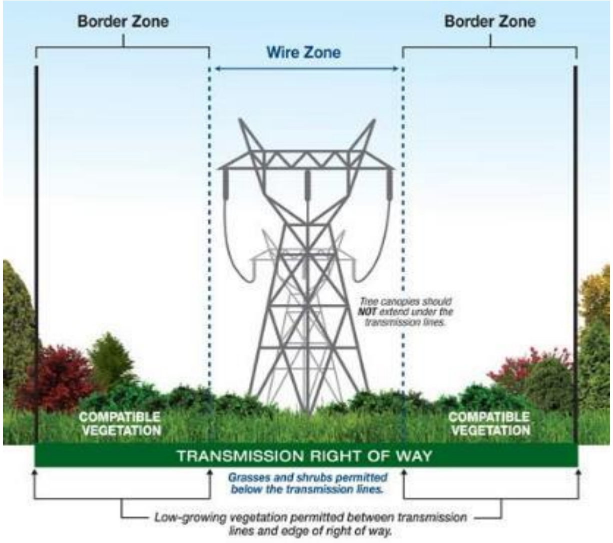
Border Zone
Wire Zone
Border Zone
Tree canopies should NOT extend under the transmission lines.
COMPATIBLE VEGETATION
COMPATIBLE VEGETATION
TRANSMISSION RIGHT OF WAY
Grasses and shrubs permitted below the transmission lines.
Low-growing vegetation permitted between transmission lines and edge of right of way.

Figure 6. An example of Right of Way for EHV Transmission Lines [39]

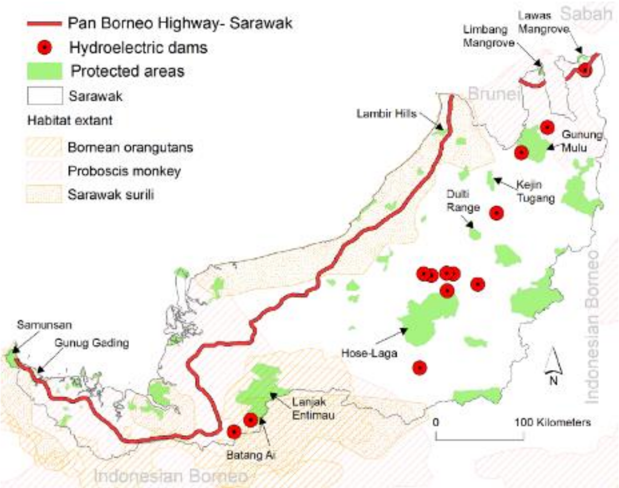

Figure 7. The Pan-Borneo Highway and hydroelectric dams in Sarawak penetrating protected areas and key habitats of threatened species in Borneo [36]

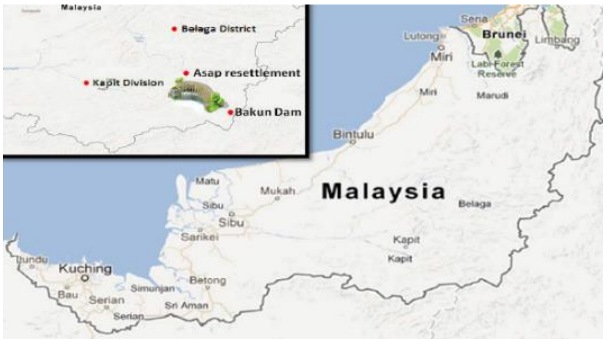

Figure 8. Map location for the Sungai Asap Resettlement Area [42]

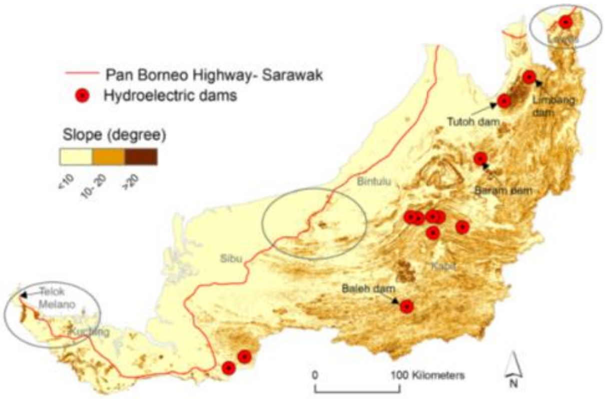

Figure 9. Pan-Borneo Highway and hydroelectric dams in Sarawak and imminent frontiers of landslides. The highway and hydroelectric dams with highly vulnerable landslide locations (circled) [36]

3. Mitigation Actions

There are different ways to mitigate the environmental impact caused by hydropower dams and such methods include a full-cost benefit appraisal of the development of the hydropower plants by the relevant authority [36]. The appraisal covers the overall cost of the project, maintenance, and support services for the relocated communities. A commonly used appraisal is the environmental impact assessment or EIA, which considers other implications on communities, culture, and economy aside from ecological impacts. [29]. However, past evidence indicated the implementation of EIA in Sarawak does not protect native customary land rights since it is not easily accessible and that the natives are disregarded from the whole assessment process [44]. Thus, stricter enforcement is needed to ensure that all responsible parties are involved in the hydropower project. One of the mitigation actions suggested was the construction of small-scale hydropower plants or even the installation of mini-hydro systems instead of large-scale ones to save space and minimize the environmental effects [5, 45]. There have been several projects covering the installation of mini-hydro systems in Sarawak, namely in Bakelalan, located at the foothills of Sarawak's highest mountain, Gunung Murud [46]. Previously, locals at Bakelalan depended on diesel-powered generators for power [47]. However, being located so inland, the access roads were difficult to come by, which lead to high costs of diesel that only kept escalating and only to be worse during the wet seasons when the access roads are rendered useless, leading to a drop in diesel supply. This motivated the construction of a mini-hydro project; the public works department (PWDS) worked in good faith and cooperation with the local communities. The Bakelalan community constructed the dam, penstock, and turbine house and laid the pipeline and after completion, PWDS distributed and managed the power network. The project ended up providing 30kW of energy that was distributed to 400 people of the Buduk Nur community 24 hours a day at the cost of RM600,000, which was a huge step up from the diesel power the community depended on that was at best run 4-6 hours daily [46]. These dams could be constructed at rivers near remote rural areas as a decentralized unit.

Aside from this, the flow of water from the reservoir can be regulated to minimize the impact on aquatic life. Minimum flow release would allow some flow below the power plant, which helps maintain the current water ecological conditions [40]. On the other hand, sedimentation can be tackled through dredging [48] or through the construction of small-scale weirs [49] that can trap sand and particles for removal. Apart from that, turbine technology could be investigated with the view of being fish-friendly to reduce the impact on the population of aquatic life. In the development of fish-friendly turbine technologies, the focus is on the mortality rates of the fish passing through the turbines. The Voith Minimum Gap Runner (MGR) was based on the Kaplan turbine, which is the conventional turbine used in the hydropower dams. The MGR has smaller gaps between the runners and the turbine walls, which helps to prevent the fish passing through from being crushed by the runners. The injury rate of fish passing through the MGR is 1.5% as compared to 2.5% for the Kaplan turbine [50]. Figure 10 shows an improved version of the MGR, the Alden turbine which enables no gap between the blades' tips and the turbine walls.

Other suggestions include a resettlement policy for the communities to be relocated. The government should compensate these communities with provisions such as land, money, and an alternate source of livelihood. Mussa et al covered-on dam removals as a mitigation method, given that it is the more frequently used management option around the world [40]. This focuses on old dams to be renovated or small dams that are no longer used. Lastly, fish nurseries can be set up to conserve aquatic wildlife. The fertilization, hatching, growth, and release can be artificially managed to sustain the population of the aquatic life.

Figure 10. Physical model of an Alden turbine runner [51]

4. Discussion

4.1 Flora and Fauna

According to our review, hydropower will pose a threat to the environment as it is especially to flora and fauna surrounding the construction area. The state already has three large dams currently operating, which are Murum, Batang Ai, and Bakun. There are more dams on the way, with one of them being the Baleh dam which was estimated to be in commission by 2025. In section 2.2, Figures 4 and 5 showed how much of the forest was left after the deforestation for the construction of the Bakun and Murum dam. As the deforestation process is necessary for the construction of the dam, an environmental impact assessment or EIA would be the alternative option to mitigate the environmental impact caused by the hydropower project.

Amidst the development of the state's power generation, there are ways that can indirectly mitigate the environmental impact of hydropower. The equipment of the dams in commission can be improved such as the efficiency of power generation by the turbine. If the efficiency of the turbine can be improved, this would reduce the area needed for the construction of hydropower dams. Other ways include minimizing the transmission loss along the power lines or increasing the efficiency of energy utilization on the receiving end of the line. This would be a cost-effective method to meet the state's energy demand without expending any additional cost on constructing new hydropower plants.

Additionally, hybrid floating photovoltaics-hydropower technology can be implemented in the hydropower dams in Sarawak to reduce the number of hydropower dams to be constructed in the future. As shown in Figure 11, the hybrid FPV-hydropower system maximizes the land used for a hydropower dam [52]. The hybrid FPV-hydropower system can generate more power than a conventional hydropower system. This would, in turn, reduce the need to construct more hydropower plants in Sarawak in the future. Furthermore, the floating solar photovoltaics used in the hybrid FPV-hydropower system is also a clean, renewable energy source and has low carbon emissions, like hydropower. Hence, the balance of the ecosystem in Sarawak in the future can be maintained.

4.2 Relocation

Following the decades upon decades of the continuous construction of hydropower dams in low and middle-income countries, there has yet to be any comprehensive remedy to cope with the severe impacts on the local people, even with the multiple frameworks developed such as the Dams and Development: a New Framework for Decision making made by The World Commission on Dams (WCD), or even sustainability guidelines launched by the International Hydropower Association (IHA) and even with the rising rate of social impact assessment techniques [53]. If any future hydropower project affects an indigenous community, the relocation process can be improved. While the dam itself may displace their home, the community may not need to abandon the river on which their livelihood depends. It may be possible for them to move downstream along the river, given that the state of the river does not deteriorate upon the introduction of the dam. Also, the government must oversee the process of relocation to ensure that an agreement can be reached between the indigenous community and the organization responsible for the construction. According to Sarawak Ordinance, whenever necessary, the power to enter on land for purposes of construction as written was to enable the works in relation to the installation of any system of distribution of energy under that Ordinance, a licensee may do works on any land other than state land. It is also stated that compensation to all persons interested for any disturbance, damage, or disability that may be caused by it would be given. Before entering any land, the licensee was required to give notice to the owner or occupier of the land stating the works that were to be done on the land; this notice was to be deemed to be properly given and sent by registered post or left at the usual or last known place of abode of the person-related. However, if the person cannot be found, the notice will be fixed conspicuously on some part of the land, the owner who received the notice was given 14 days upon placement of the notice to lodge an objection. The objection lodged shall allow an inquiry to be held by the Director of Lands and Surveys to hear out all parties before deciding either to unconditionally or subject to terms, conditions and stipulations, as he thinks, is fit and authorize or prohibit any acts mentioned in the notice. If an objection is not lodged within the time limit of 14 days, the licensee may immediately enter the land and do all the acts specified in that notice [54].

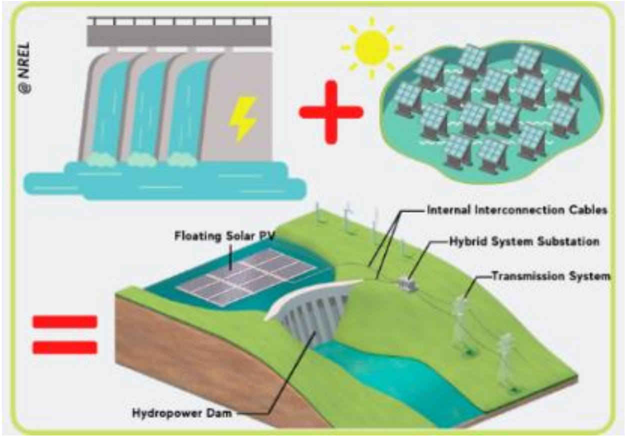

Figure 11. A hybrid FPV-hydropower system could be implemented in existing hydropower dams in Sarawak [52]

In Sarawak, we can draw the case of the Bakun dam, where around 50% of the impounded land was lands claimed under customary rights and the cost of resettlement was funded by the Federal Government while the actual implementation of the resettlement would be undertaken by the State Government. In terms of farm compensation, it would be given according to the number of fruit trees. It was discovered that the rate changes that were initially promised were around RM50-52 per tree, however, the final compensation was around RM5-9 or RM 30, according to different villagers interviewed. There was also individual compensation for people born in 1998 where they were given RM13,000 per person, and compensation for burial grounds where those who wanted to move the grave were given a compensation of RM4000 and RM 1500/2000 to not move the grave [55]. Despite that, these payments have been criticized for not being a more sustainable method of compensation for the people that were removed from their lands [56]. The compensation that was received by the locals was perceived as too little, which was mainly due to the land compensation because now, each family was only provided with three acres of land in the resettlement sites as compensation for the lost land that was used as the reservoir area which had been voiced out [56, 57]. Thus, it would be wise for the government to have plans in place to give out proper compensation to be given to smoothen the relocation process while reducing the social impact to as little as possible. A system that reconstructs the tendering methods needs to be adapted to entice participation from local communities since, with a different approach, one can minimize the potential of corruption related to the management of high volumes of the public participation in energy supply [58].

At the same time, from a social policy perspective, we can see the positive effects of the relocation of the locals that were located in the reservoir area since they were now given access to better welfare services. At the resettlement site, people are given easier access to roads, clinics, and schools where the people previously had to travel by boat for an entire day just to reach the hospital.

4.3 Sedimentation and Greenhouse Gases

The sedimentation levels in Sarawak are especially high due to deforestation, which causes erosion of soil, causing the river waters to be murky. The amount of GHG released from the sediments found within hydropower dams was reviewed under section 2.1, and it was found that the GHG emission in Sarawak is the largest compared to Peninsular Malaysia at 60.9%. Majority of which is contributed by Bakun dam due to its large surface area of 695km^2. Thus, the contribution of GHG emission due to HEP from the upcoming Baleh dam is expected to be high as well since the projected surface area is 588km^2. Additionally, more major HEPs are planned for Sarawak under SCORE projects as well. However, the GHG emissions due to HEPs are still significantly lower than thermal power plants at 11g of CO_2 per kWh generation compared to 943g of CO_2 per kWh generation of coal-fired power plants [59].

As discussed under section 2.1, sedimentation also indirectly affects the lifespan of the hydropower dams. Since the sedimentation levels are high in Sarawak rivers, as evident from the annual inflow of 9,000,000 tons of sediments settling into the reservoir of Bakun dam, the lifespan of Bakun Dam is estimated to be only 50 years [60]. While Sarawak has yet to decommission any of its dams, the environmental impacts of dam decommissioning should be taken into consideration as the Batang Ai dam, which was commissioned in 1985, is nearing its end-of-life expectancy, accounting for the 50-year lifespan of Bakun Dam. Hydroelectric dams can be repurposed after they are decommissioned as a water supply for irrigation and commercial uses, as well as recreation sites for tourism. These would require the lowering of the decommissioned hydroelectric dams. Some decommissioned hydroelectric dams which are demolished would require the restoration of rivers.

Since sedimentation contributes the most to greenhouse gas emissions of HEPs, the issue can be solved in multiple ways. One of the ways to remove sediments is through periodic mechanical dredging. This method utilizes dredgers, which are machines that are specialized in removing sediments that lie in water bodies. This should help in reducing the accumulation of sediments in the long run. To assist in catching the sediments, small-scale weirs can be constructed to trap them for removal in the future. Another method that can be implemented is the installation of a dedicated channel or canal in the dam to flush sediments periodically. This should help regulate the sediment build-up and ensure that GHG gas emissions are controlled. To tackle the emission of greenhouse gases from the sediments after demolishing the hydroelectric dams, the dig and dewater approach can be implemented where the decommissioned hydroelectric dam is drained, and the dried sediments are removed from the location.

5. Conclusion

To summarize, hydropower plants pose a threat to Sarawak's forests, rivers, and the communities living nearby the dams. The felling of trees and impoundment of the dam leads to soil erosion and major loss, which will inevitably negatively impact the ecosystem of Sarawak, leading to the extinction of some flora and fauna species that are endemic to Sarawak. As Sarawak is bound for the construction of more major hydropower dams, this would mean a lot of forests would be submerged in the future. Sarawak would then require proper management such as the EIA to ensure that their ecosystem is preserved in the future. Aside from the forest ecosystem, indigenous communities living by the rivers are also affected and must be relocated to allow the project to progress. Oftentimes, these communities are not properly compensated upon relocation, and the people that were relocated before were unable to obtain proper compensation. These people had to reach out for legal methods through the court to obtain somewhat fair compensation for their relocation from their original lands. It is imperative for the government to give proper compensation that is planned well to satisfy these communities and ensure that they are conforming to the norms of a functioning society in future relocations that may occur when constructing a dam. It is also vital for the government to ensure the organization in charge of the hydropower project obtains a consensus from the indigenous communities who are to be relocated. This would ensure that both sides can negotiate the terms and conditions of the relocation process and compensation and that the communities are not left out throughout the entire process of the project. Although hydropower is portrayed as a clean source of renewable energy, there are still GHG emissions associated with it through sedimentation, albeit at a much smaller scale compared to coal-fired power plants. The impoundment of the dam slows the flowing river current, which disrupts the natural sedimentation inflow and outflow, creating an imbalance that causes it to accumulate in the reservoir. Sedimentation indirectly affects the lifespan of HEPs by decreasing the dam capacity and increased wear on the machinery. A large amount of sedimentation discharged during decommissioning will potentially threaten the ecosystem downstream from the HEPs and cause some rivers to become shallow and eventually dry out. Hence, sediment management is a must in HEPs to ensure the lifetime of the dam as well as to keep the environment safe. The HEPs in Sarawak must be monitored and maintained regularly in the future as the dams are so big that any cracks in the dams may cause the entire state to be flooded if the dams were to experience total failure. In the distant future, Sarawak may need to prepare other renewable energy alternatives to hydropower, such as solar power plants or wind farms, as the estimated lifespan of hydropower plants in Sarawak is about 50 to 70 years. The oldest HEP in Sarawak, which is the Batang Ai dam, is nearly three-quarters of its estimated lifespan. Additionally, Sarawak can look into the potential of hybrid FPV-hydropower systems to be integrated into the existing HEPs to reduce the reliance on hydropower. Currently, there are many hydro projects being planned in Sarawak, and these planning must be taken seriously in Sarawak to keep Sarawak's rivers and forests safe in the future. These mitigation methods have to be further studied to enable the government to have more control over the construction of these hydroelectric dams, which ultimately, as a renewable source of energy, has more to be desired. Especially in a developing nation like Malaysia, a breakthrough would likely enable a sustainable future in terms of power generation in the long run.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

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